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Optimization Of Process Parameters For Incremental Forming Of Aluminium 1060

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Abstract-
In the past two decades, extensive research was done on incremental sheet forming (ISF). It has resulted in significant advances in fundamental understanding and the development of new processing and tooling solutions. However, ISF is yet to be fully implemented in mainstream high-value manufacturing industries due to a number of technical challenges, all of which are directly related to ISF process parameters. Now a days, the demand for new materials for sheet plate has become high in the number of applications because of various attributes in the material such as high tensile strength, good flexibility and durability. The present work gives the effect of several process parameters such as tool rotating speed, step size(z-axis), and feed (x-y axis) on forming force of incremental forming. Particular attention is given to the deformation rate and stress developed in the material during incremental forming. The tool path for incremental forming is generated using MATLAB software. Simulations are done using Taguchi's L9 orthogonal array method. All the simulations are done in Abaqus software. Stress developed in the material during incremental forming is determined in the simulations. The effect of each process parameter on the stress developed is investigated. Finally, Optimization of the Process parameters is done for Incremental forming process. ANOVA technique is used to find the influence of each process parameter on the stress developed in the material

Keywords – *Single Point Incremental Forming (SPIF), Design of Experiment (DOE), Analysis of Variance (ANOVA)*

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I. INTRODUCTION

The incremental Forming process is a flexible and versatile process with a promising future in batch manufacturing and mass customization. Traditional sheet metal forming processes usually involve high costs due to the design and manufacturing processes involved in it, moreover, the design of the die is unique for every individual component. The contemporary sheet metal industry employs forming methods which use a precise punch and dies to form components with precise tolerances. In mass production, the high cost involved in the manufacture of dies and punches are absorbed by the number of components formed, whereas this is not the case for low-volume production which increases the manufacturing cost of products in low-volume production. To solve this, the Incremental forming process –rapid sheet metal forming process has been introduced and is under research for a couple of decades. This process still needs to be improved in accepts of accuracy and product quality. ISF process needs the following in most cases: a simple tool, a fixture for holding sheet material and a universal Computer Controlled Machine (CNC) machine.

In many cases, the ISF process is done with a help of CNC-controlled machines. A minimum 3-axis CNC machine is needed to control the path of the forming tool along the predefined contours at different levels. Milling machines are the most commonly used because they allow high speed, large working volumes and good stiffness. For an axis-symmetric part (SIF) a CNC lathe is suitable to perform the process in less time, but also a CNC milling machine can be used.

More than that, some researchers or companies also developed or proposed some machines, which were specially built for the ISF process. In 1996, an industrial company developed the first prototype machine and continued to develop it until 2002 when they started to provide specialized equipment for industry. Industrial robots are frequently used for the ISF process. They have benefits like large working volume and much more flexibility than a milling machine, but also some disadvantages, low stiffness and low capacity to apply big forces. Using robots in incremental sheet forming was patented by Tuominen and he describes many configurations with one or two robots, for both SPIF and TPIF technologies.

Nowadays customer requirements are permanently changing and according to them the tendency in the modern industry is to implement flexible manufacturing processes. Incremental forming can fulfil the individual needs of the customer at a lesser cost. Research on the effect and variations of these process parameters were analyzed on various material. But there are several types' of materials & alloys etc. are available and updated every few days for incremental forming for various applications. So, optimization of process parameters for different materials should be done in order to decrease product cost and increase product quality, accuracy, and productivity. Process parameters should be optimized for different materials to do incremental sheet-forming process effectively

II. EXPERIMENTAL SETUP AND PROCESS

Selection of Process parameters

The present work aims at finding out the impacts of different input factors on the response characteristics of the SPIF process. In this study, optimization of input factors has been performed to produce conical frustums with helical tool paths using the Taguchi technique. The first step of optimization is to select input parameters for investigation of their effects on output parameters. Optimization of these process parameters such as feed rate, spindle speed, and step size will be carried out by taking three levels of each parameter and forming simulations by using the L9 (3X3) Orthogonal Array.

Table 2.1: Process parameters selected for Experiments

Process parameters	Level 1	Level 2	Level 3
Feed rate (mm/min)	200	400	600
Spindle Speed (rpm)	0	500	1000
Step size (mm)	0.5	1	1.5

Design of Experiments

After selecting the required parameters are chosen, the simulations are done on Abaqus software according to Taguchi's L9 orthogonal array. The simulations are done as per the following table and the maximum stress developed is determined for each case.

Table 2.2: Taguchi's L9 Design of experiments for the simulations

S. No	Spindle Speed (rpm)	Feed rate (mm/min)	Step size (mm)
1	0	200	0.5
2	0	400	1
3	0	600	1.5
4	500	200	1
5	500	400	1.5
6	500	600	0.5
7	1000	200	1.5
8	1000	400	0.5
9	1000	600	1

Generation of Tool path using Matlab

The tool path required for incremental forming is generated using the Matlab program. The toolpath for the tool is a spiral path with varying step size is generated. From the spiral tool path, the amplitude plot required for the toll is generated. The X, Y and Z coordinates specify the path travelled by the tool to generate a cone. The modifications are made in the Matlab code to generate the cone-shaped tool path for different step sizes as per the process parameters selected. The X, Y and Z coordinates generated using the code are used for carrying out simulations in the Abaqus software.

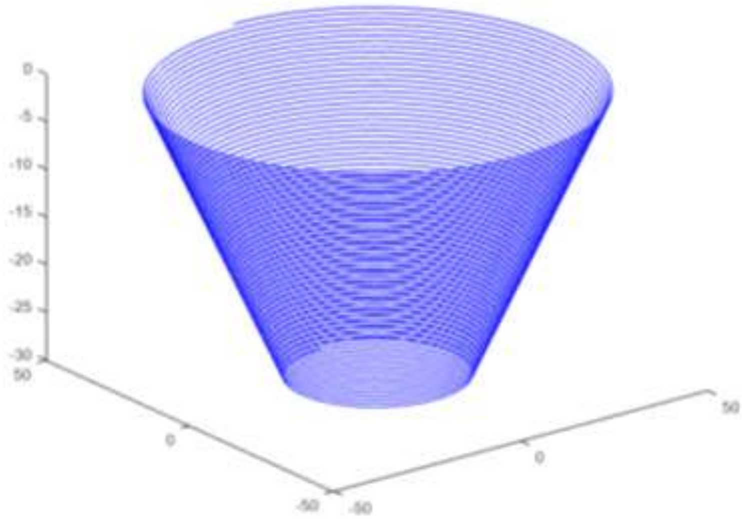


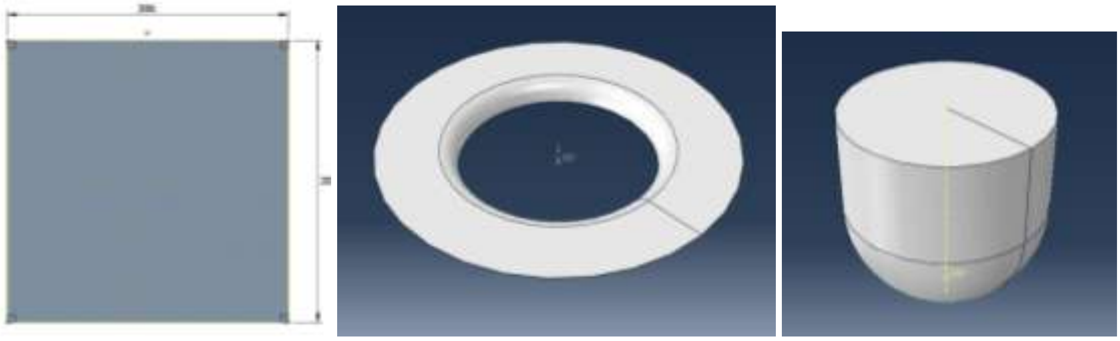
Figure 2.1 Tool path generated using Matlab

Table 2.3: Amplitude plot for the tool along X, Y and Z

S.No	X	Y	Z
1	50	0	0
2	49.98961	0.872572	-0.00278
3	49.96399	1.744781	-0.00556
4	49.92315	2.616362	-0.00833
s	49.86712	3.487049	-0.01111
6	49.7959	4.356577	-0.01389
7	49.70952	5.224681	-0.01667
8	49.60801	6.091097	-0.01944
9	49.4914	6.955562	-0.02222
10	49.35972	7.817812	-0.025
11	49.21303	8.677585	-0.02778
12	49.05137	9.534619	-0.03056
13	48.87478	10.38865	-0.03333
14	48.68332	11.23943	·0.03611
15	48.47705	12.08669	-0.03889
16	48.25604	12.93017	-0.04167
17	48.02036	13.76962	-0.04444
18	47.77008	14.60478	-0.04722
19	47.50527	15.4354	-0.05
20	47.22603	16.26122	-0.05278
21	46.93243	17.08201	-0.05556
22	46.62456	17.89749	-0.05833
23	46.30253	18.70744	-0.06111
24	45.96643	19.51159	-0.06389
25	45.61637	20.30972	-0.06667
26	45.25245	21.10156	-0.06944
27	44.87479	21.8869	-0.07222

Simulations on Abaques:

The simulations are done by using the tool path generated in Matlab. A total of 9 simulations are done as per Taghuchis's design of experiments. The 3d model of the sheet, support and Tool are modelled. The material property, interaction and boundary conditions are given as input.



a b c

Figure 2.2 3D Modeling of a)Sheet b)Support c)Tool

All the simulations are done by varying the process parameters as mentioned in the design of experiments. The deformation plot is obtained for all the simulations. The maximum stress developed in the sheet is recorded for further optimization of the process parameters. The deformed shape plot is shown in the figure below.

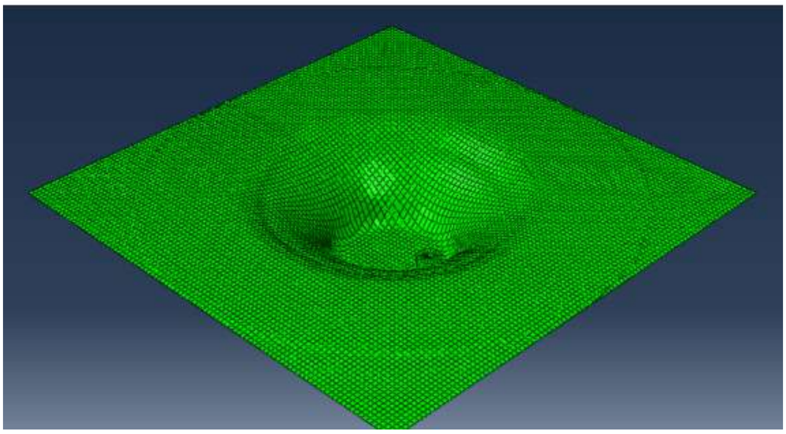


Figure 2.1 Deformed shape plot of the simulation

III. RESULTS AND DISCUSSIONS

Based on the L9 orthogonal array, simulations are done. The effects of spindle speed, feed rate and step size on maximum stress developed on the sheet are determined. The output values are shown in the table below

Table 3.1: Results obtained after performing the simulations

Run order	Spindle Speed (rpm)	Feed rate (mm/min)	Step size (mm)	Maximum Stress developed (MPA)
1	0	200	0.5	674.7
2	0	400	1	776.8
3	0	600	1.5	811.8
4	500	200	1	703.4
5	500	400	1.5	645
6	500	600	0.5	708
7	1000	200	1.5	720.4
8	1000	400	0.5	779.4
9	1000	600	1	808.2

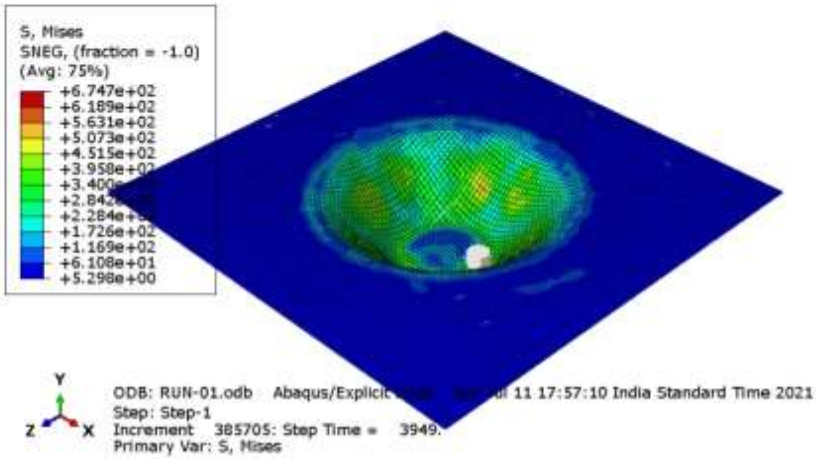


Figure 3.1 Results of the simulation done at spindle speed 0 rpm, feed rate 200 mm/min and step size 0.5 mm

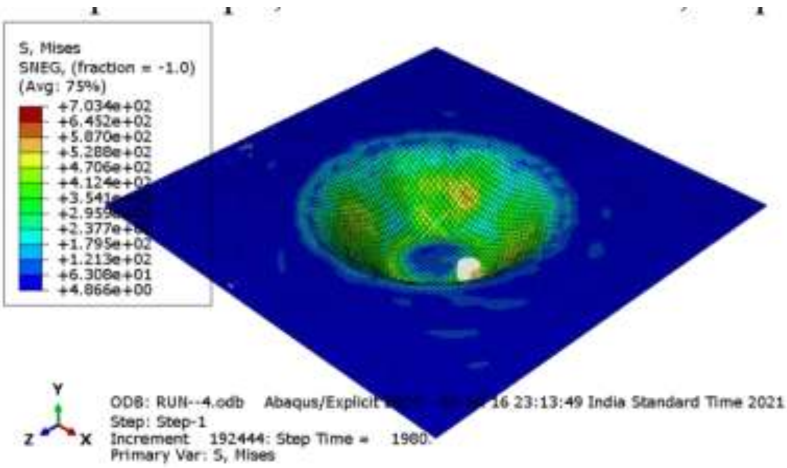


Figure 3.2 Results of the simulation done at spindle speed 500 rpm, feed rate 200 mm/min and step size 1 mm

After performing the simulations, the obtained results are used for optimizing the output parameters. The main effect and interaction effect plots are generated. The Analysis of variance (ANOVA) is done to find the significance of the input parameters on the maximum stress developed. The optimized values obtained are 525.25 RPM for spindle speed, 284.84mm/min for feed rate and 1.5mm for the step size.

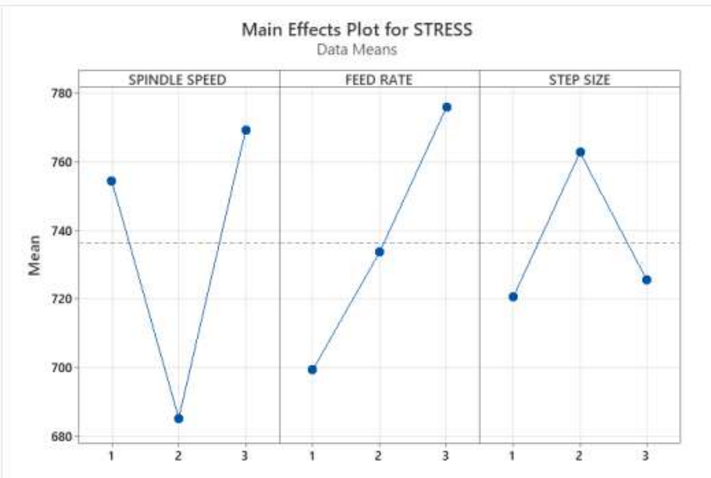


Figure 3.3 Main Effect plot for the selected process parameters

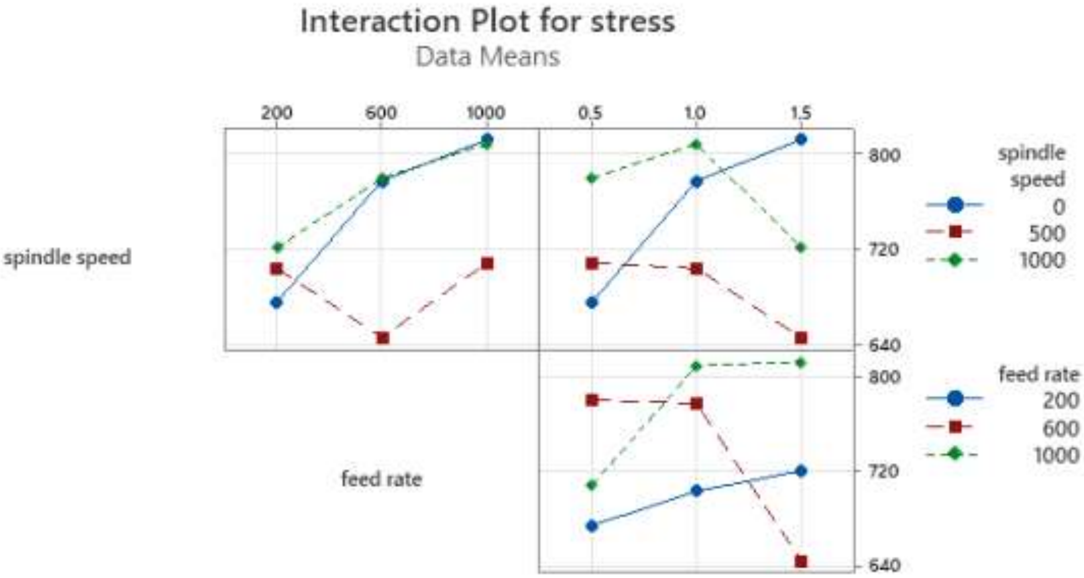


Figure 3.3 Interaction plot for the selected process parameters

Table 3.2: ANNOVA results for the selected process parameters

Parameter	DF	Adj SS	Adj MS	F-value	P-value	% contribution
Spindle speed	2	8818	6011	1.90	0.278	15.46
Feed rate	2	12022	4409	2.59	0.344	79.35
Step size	2	3166	1583	0.68	0.594	5.18
Error	2	4634	2317			0.01
Total	8	28641				100

IV. CONCLUSION

After performing the simulations, It was observed that when the feed rate increases, stress developed in the material also increases. The effect of feed rate is more as compared to tool rotational speed and step size. As tool rotational speed increases stress developed in the material decreases. As step size increases stress developed in the material increases but its effect is small compared to the effect of feed rate. Simulations of Incremental sheet forming by the CAE approach are effective to determine the most influencing process parameters. From the levels of the process parameters considered for the study, the optimized values of process parameters are 525.25 rpm (spindle speed), 284.84 mm/min (feed rate), and 1.5 mm (step size).

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